Waves, Turbulence and Boundary Layers

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LONG-TERM GOALS

The long-term goal is to develop the equations and the detailed rules so that three-dimensional numerical ocean circulation models can interact with surface wave models. This has not been previously possible since the interaction terms (e.g., wave radiation stress terms) are, a priori, vertically integrated (Phillips 1977) and the non-wave induced velocities have been assumed to be vertically constant.

OBJECTIVES

1. Develop three-dimensional, wave energy and momentum equations and the concommitant interaction terms.

2. Develop rules from derived or existing empirical information for surface and bottom wave dissipation, surface wind stress forcing for waves and currents and other unknowns. Develop a coupled wave-current numerical model.

3. For turbulence closure models that make use of the turbulence kinetic energy equation (e.g., the so-called Mellor-Yamada model, 1982) determine the changes that must be made to recognize surface waves.

APPROACH

Although the objectives are listed in logical progression, as in most scientific discovery, the simpler objective 3 has been addressed first and the not so simple objective 1 addressed second. Objective 2 will be the subject of research in the next year or two.

WORK COMPLETED

I had previously developed a new way to account for the effect of surface waves on turbulent bottom boundary layers, bottom friction and conversely wave dissipation (Mellor 2002). Calculations that resolved the temporal variation of oscillations induced by waves (time steps of about 0.05 s), and which were favorably compared with data, were used to provide additional shear production for the turbulence kinetic energy equation when the oscillations were not resolved (time steps for three-

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dimensional circulation are of order 10s of minutes). The additional shear production is a function of oscillation amplitude and frequency, bottom roughness and angle between the mean current and the oscillations, all presented in non-dimensional form. The formulation has recently been improved to more accurately apply to coarsely resolved vertical grids and will be published sometime in the future.

Surprisingly, surface wave equations appropriate to three-dimensional ocean models have not been presented in the literature; only vertically averaged equations have been available (Phillips 1977) and are not suitable for wave models interacting with three-dimensional circulation models. To correct this deficiency, a new paper on wave-current interaction, after substantial revision this year, has been published (Mellor 2003).

A new paper (Mellor and Blumberg 2004) adopted the Craig-Banner wave breaking parameterization whereby turbulence energy due to wave breaking is injected into the top of the surface boundary layer. Correspondence between the principal empirical assumption of Craig and Banner and the data of Terray et al. (1996) was demonstrated. As used in the Mellor-Yamada turbulence closure model (1982), the effect of wave breaking is to deepen summertime surface boundary layers and lower summertime sea surface temperatures.

RESULTS

I believe the paper, "The Three-Dimensional, Current and Surface Wave Equations" (Mellor 2003) is an oceanic science breakthrough. Expressions for vertically dependent radiation stresses and a definition of the Doppler velocity for a vertically dependent current field are obtained. Other quantities such as vertically dependent surface pressure forcing are derived for inclusion in the momentum and wave energy equations. The equations include terms representing the production of turbulence energy due to currents and waves.

IMPACT/APPLICATIONS

One can envision creation of fully interactive three-dimensional ocean circulation models and wave models such as WAM, SWAN or WAVEWATCH. We will first couple one of these models to the Princeton Ocean Model (POM) and therefore make a coupled model available to the 2000 POM users. However, the interface between any circulation model and any wave model should become generic thereafter.

RELATED PROJECTS

The work, here tied to CBLAST, is related to the NOPP Surf Zone Project, which motivated the paper on oscillatory boundary layers (Mellor 2002), which is specialized to very shallow water. Now, the new 2003 paper should provide under pinnings for the type of work by John Allen and Priscilla Newberger for shallow water but is also aplicable to deep water as well. Thus the work for CBLAST and for NOPP has merged.

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